An Overview Of Digital Audio Broadcasting Systems

Eureka! Unraveling The Mysteries Of This 21st Century Medium

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Radio's tradition of providing entertainment and information to people around the world has been given a new lease on life with the move to digital broadcast radio, which is now becoming a revolution in technology. This article provides an outline of emerging digital radio technology. In it, we'll cover digital audio broadcasting (DAB), which replaces the traditional "analog" AM and FM systems with higher fidelity, greater noise immunity, and new services.

Digital Radio, or DAB, as it's sometimes called, is a method of broadcasting and receiving radio signals in the digital domain, as opposed to the traditional method of analog transmission by AM and FM systems. While digital television signals are now routinely received over cable and satellite systems, reception of digital *radio* broadcasts is still fairly uncommon. Although not yet a reality in the United States, digital radio broadcasts are available in many other parts of the world, such as Europe, Asia, and Canada. Digital radio is most prevalent in Europe, most notably the UK, where the BBC simulcasts much of its programming in digital.

Supporters of the format say that digital is the future of radio and that it is inevitable. While a large portion of the industrialized world has access to digital radio signals, very few people are taking advantage of it yet since new hardware, in the form of a digital radio tuner (DRT), is required.

How It Works

Digital radio works similarly to satellite TV, except that instead of being transmitted from a satellite, it is normally broadcast from transmission towers just like standard radio. Two companies, Sirius Satellite Radio, Inc., and XM Satellite Radio Holdings, Inc., offer satellite-based subscription radio services (something like DTV), but for the purposes of this article, we'll concentrate on the more widely available conventional broadcast version of digital radio.

In contrast to analog radio, digital radio signals are immune to distortion from multipath, adjacent stations, overly weak or overly strong signals, etc. Additionally, digital radio signals can carry extra information, such as text, that can provide station callsigns, artist and song titles, weather, or even traffic information.

A number of technologies are being developed to deliver DAB services via terrestrial and satellite means. At this stage, two types of DAB technology are potentially available for delivery of terrestrial services: Eureka 147 and in-band. Eureka 147 is the only system presently in operation and can deliver satellite services to receivers used for terrestrial services. In-band systems are under development in the United States.

The Eureka 147 System

When DAB was first presented as a concept called the "Eureka System," it was envisioned as a digital signal that would be transmitted on available frequencies within the "L Band" (300 to 1500 MHz). Eureka 147 was developed in Europe by a consortium of broadcasters. The system uses advanced digital techniques to convert the audio signal from an analog waveform to a digital signal, sampling the amplitude of the wave and creating a stream of ones and zeros, which accurately represent the original sound. The sampled information is digitally compressed, and several audio channels are brought together and encoded into a single data stream by means of a multiplex. Data and other services are added. The whole digital stream is referred to as an ensemble. Receivers separate and decode the signals in the digital stream.

The method of transmission could be either satellite-based (extra-terrestrial), whereby the signal would be uplinked to a satellite and distributed to satellite receiver, or an earth-based (terrestrial), antenna system, whereby a given number of stations could transmit from a central site to receivers in the immediate area. But, in order to accommodate the large number of urban AM and FM stations already in place, the data transmissions would have to be compressed in order for them to fit into the limited spectrum available to them. However, the efficiency and reliability of the data compression facility employed would be the determining factor as to how many stations would, realistically, be able to transmit from any one site.

This system broadcasts at much higher frequencies than standard radio transmissions, which operate in the FM band, from 88 to 108 MHz, and in the AM band, from 0.525 to 1.705 MHz. While the actual frequencies used for digital radio depend on the availability for that particular country, Britain utilizes Band III, which covers 174 to 240 MHz while Canada uses part (1452 to 1492 MHz) of the L-Band, which is 300 to 1500 MHz. In comparison, satellite television utilizes frequencies starting around

4 GHz and going up to almost 20 GHz.

The Eureka system broadcasts multiple stations and services over a single frequency in something called a "multiplex." Bandwidth within the multiplex can be allotted to the various stations as needed. For instance, a high-quality stereo station can be given more bandwidth than a news or talk radio station that may be broadcast in mono. Stereo programming is typically broadcast at 192 kilobits (kbit). Digital radio uses a method of digital compression (similar to that of MP3) so that many services can be combined onto one signal for broadcast over a single frequency.

The sound quality of digital radio has been described as close to or as good as CD. With a bandwidth of 192 kbit for a stereo broadcast, the sound quality of digital radio, which utilizes MUSICAM digital compression, should be quite good but probably not true CD quality. The main advantage of digital radio is that it will not have the usual distortion associated with analog radio, such as hissing, popping, and phasing.

Eureka 147 will operate in a new band, automatically avoiding any impairment caused to, or suffered from, existing analog services. The In-Band systems showed particularly badly with respect to the key attribute their proponents have always touted: their ability to co-exist in the AM/FM bands without causing interference to analog services.

Eureka 147 generally allows for more effective spectrum use than analog technology in terms of the number of services that can be carried in a given amount of spectrum and in providing adjacent local coverage areas.

Canada, Australia, and a number of European countries, including the UK, have commenced services using Eureka 147. Major radio manufacturers have obtained access to the proprietary Eureka 147 technology.

Depending upon the technical arrangements, the Eureka 147 system may offer:

- More reliable reception to fixed, portable and mobile receivers than current AM or FM radio
- Higher quality sound than AM or FM radio, provided that an appropriate bit rate is used
- Program associated information and ancillary services
- Use of one receiver for both terrestrial and satellite reception
- The capability to reconfigure services for different programming requirements
- More effective use of spectrum than analog services
- Reduced radiated power requirements over analog services for coverage of a given area
- Greater flexibility in coverage than analog services
- The ability to operate over a range of frequency bands
- Generally lower or comparable capital and operating costs compared to AM or FM radio.

In-Band, On-Channel (IBOC) System

The two main in-band systems under development are In-Band, On-Channel (IBOC) and In-Band, Adjacent Channel (IBAC). The IBOC system transmits a digital signal simultaneously within an existing analog AM or FM signal (see **Table 1**). The IBAC system transmits a digital signal within unused spectrum adjacent to that used by existing FM signals. In-Band, Reserve Channel (IBRC), which is based on using "spare" spectrum that can't be used for other services, is also a possibility.

Unfortunately, the United States has decided not to adopt the Eureka system for digital radio and is developing its own system, IBOC, which is compatible with the current analog radio formats. This method will utilize the existing AM and FM bands by attaching a digital side-band signal to the standard analog signal so that the system is compatible with any existing tuner. Thus, if a station is currently located at 99.9 on the FM band, it will remain at 99.9 FM whether in analog or IBOC digital radio. Because of the limitations of the bandwidth of AM frequencies, digital AM broadcasts are said to have FM-like sound quality, while digital FM broadcasts will have near-CD sound quality. IBOC uses a form of digital compression called Perceptual Audio Coder (PAC), originally developed by Lucent Technology. Another limitation of IBOC is that AM and FM frequencies are not suitable for satellite transmission if extraterrestrial transmission is desired in the future.

The characteristics of in-band systems are a subset of the characteristics of Eureka: CD and high-quality stereo sound, plus ancillary data, text, and other new services.

Using the existing AM and FM bands has both advantages and disadvantages, but the biggest disadvantage of the IBOC system is its incompatibility with the Eureka digital radio systems in use throughout the world.

The IBOC system is unique in that it would coexist on the same channel as the existing FM or AM station. Unfortunately, in order to do this on the FM band, it would consume more bandwidth, thereby causing a possible compromise of the 100-KHz guard band that now exists between each station on the dial. This is not likely to be acceptable, given that many listeners, unconvinced of the effectiveness of digital radio, would still be listening to their FM receivers. As for AM, if an IBOC system were to be introduced for it, a similar situation would exist.

The IBOC approach to digital radio uses the current AM and FM frequencies to simultaneously transmit digital signals along with the current analog transmissions. This makes the technology compatible with existing radios. New digital-capable receivers will produce CD quality audio on FM stations and better than FM quality on AM stations. If a station elects to turn off the analog signal in the future, IBOC DAB-compatible receivers will operate with the remaining all-digital signal. IBOC signals are designed so that for each station, the IBOC signals fit within the frequencies and spectral occupancy allowed for that station's conventional AM or FM transmissions.

DAB Type	Technical Features	Typical System
New Band Approach	System used new spectrum different from what is currently allocated for terrestrial radio service	Eureka/147
In-band on-channel (IBOC) approach	Spectrum of the digital signals are placed in occupied channels within the existing FM spectrum	AT&T/Amati IBOC USADR FM-1 IBOC
In-band adjacent channel (IBAC) approach	Spectrum of digital signals co-exist with analog FM signals in the existing analog FM spectrum	AT&T IBAC

Table 1. Current DAB systems.

It is expected that IBOC digital radio, in addition to CD quality sound without multipath interference, will be capable of transmitting a large volume of ancillary data. Potential applications for ancillary data include station data, such as callsign, format, artists and song titles, as well as news, financial, and stock market data, paging, dispatching, computer communications, and networking.

In addition to ancillary data, it is expected that digital radio will be capable of monitoring signal strengths and use this information to switch automatically from a fading signal to a new, more powerful one.

Lucent Digital Radio, a wholly owned venture of Lucent Technologies Lucent Digital Radio is developing its IBOC DAB system for consideration as a potential digital radio standard in the United States. The IBOC approach will allow broadcasters to rapidly introduce digital audio programming to listeners on their current dial positions using existing transmitters and antennas. In addition, the system will support datacasting using the existing radio broadcasting infrastructure to deliver information, such as song titles, weather and traffic reports, financial reports, and news, to consumers with new digital receivers.

Lucent Digital Radio draws on a number of patented Lucent digital audio and channel coding techniques that provide robust digital signal delivery in an impaired broadcast channel, including:

- Lucent's PAC technology
- Unequal Error Protection, which prioritizes information based on its impact on audio quality
- Multi-Streaming—a combination of techniques that extends the coverage of digital signals by allowing for graceful degradation of audio quality

Frequency Spectrum For Digital Radio

There are a number of broadcasting spectrum allocations being considered by individual overseas countries for the introduction of Eureka DAB. The main spectrum options being considered include:

- The frequency band from 1452 to 1492 MHz, allocated at the World Administrative Radio Conference (WARC-92) for terrestrial and satellite uses (commonly referred to as the L-band);
- Existing terrestrial AM and FM terrestrial radio frequency bands
- Existing terrestrial TV broadcast band frequencies (VHF Band III)

The L-band is allocated internationally (except for a small number of countries, most notably the United States and the Russian Federation) for terrestrial and satellite DAB. It is also allocated to other services, including fixed and mobile services.

The AM and FM radio bands are being used for in-band digital radio in the United States. Some consideration is being given to using Eureka 147 in the FM bands, but this requires prior clearance of existing FM broadcasters. VHF band III, around 220 to 230 MHz, is being used by some European countries and India for terrestrial digital radio services.

EIA Performance Test Results On DAB Systems

On August 22, 1995, the Digital Audio Radio Subcommittee of the Electronic Industries Association (EIA) released the results of independent laboratory tests conducted on seven proponent DAB systems. Measurements and related audio recordings for each system were made at NASA's Lewis Research Center (LeRC) in Cleveland, Ohio. Subjective assessments of the audio recordings were carried out at the Communications Research Center (CRC) in Ottawa, Ontario, under contract to the EIA. These tests are the first time all proposed DAB systems were assessed by an independent body using the same evaluation criteria.

The main purpose of the laboratory tests was to determine the basic digital audio quality produced by each system, its reception reliability, and its ability to co-exist with other radio stations, including the "host" analog station. In cooperation with the National Radio Standards Committee (NRSC), the EIA developed a complex series of tests to determine these factors. Each proponent had the opportunity to propose system-specific tests that would best illustrate its operating features. All system proponents took an active part in the subcommittee that developed the testing procedures. Each system was operated in accordance with the developer's specifications, and tests were conducted using DAB encoders and receivers that were supplied by the proponents themselves.

The DAB systems (and modes) listed were evaluated in the EIA tests (see **Table 2**). All comments and observations in this report relate only to the first seven system proponents listed, that is Eureka 147 and the six IBOC proponents. The AT&T IBAC system is not a serious contender for a North American standard, as it utilizes adjacent FM channels and evidently would require significant frequency reshuffling in most radio markets to make it practical.

The VOA/JPL system is not discussed here, since it is designed for satellite-delivered DAB in the 2.3-GHz band, allocated only in the United States and India. This system was used by India in their DAB satellite GSAT-1, which was launched by their first Geo-orbit carrier GSLV in 2000. However, this mission failed due to some problems in final cryogenic stage.

When the basic digital audio quality of each proponent is assessed in a lab setting, using strong signals and no induced impairments, the ratings for all system proponents, with the exception of the USA Digital AM IBOC system, are quite similar. The Eureka 147 system (224 kbits/sec) rated the highest of all, even though the two USA Digital FM systems employ a higher data rate (256 kbits/sec) and use the same MUSICAM audio coding system. Even with strong signals and no interference, the USA Digital AM IBOC system suffers audio quality impairments that experts judge to be "annoying"; consequently, this system is not capable of providing "CD-Quality" DAB service.

Although all DAB receivers require time to recover when signals fail or listeners change frequencies, the recovery time of IBOC receivers is far too long to be practical in a real-world environment. The Eureka 147 system generally recovers from signal loss in one second or less. The IBOC systems can take from five to nine seconds to recover.

When tested with five common household, portable, and auto receivers with known operating characteristics, IBOC FM DAB produces significant impairments to existing analog services on first and second-adjacent channels. In a majority of the tests, expert listeners judged the stereo FM analog service to be "worse" or "much worse" when an adjacent-channel station, carrying an IBOC DAB service, is present. This interference tends to worsen when multipath occurs.

FM stations operating one channel apart on the dial are said to be "first-adjacent," while those separated by two channels are "second-adjacent." Multipath

System Name	Source Coding	Data Rate	System Type	Proposed Band Used
Eureka 147	MUSICAM	224	New-Band	1452-1492 MHz
Eureka 147	MUSICAM	192	New-Band	1452-1492 MHz
USA Digital FM-1	MUSICAM	256	In-Band, On-Channel (IBOC)	88-108 MHz
USA Digital FM-2	MUSICAM	256	In-Band, On-Channel (IBOC)	88-108 MHz
USA Digital AM	MUSICAM	92	In-Band, On-Channel (IBOC)	525-1705 kHz
AT&T/Amati LSB	PAC	128	In-Band, On-Channel (IBOC)	888-108 MHz
AT&T/Amati DSB	PAC	160	In-Band, On-Channel (IBOC)	88-108 MHz
AT&T	PAC	160	In-Band, Adjacent Channel (IBAC)	88-108 MHz
VOA/JPL	PAC	160	Direct Broadcast Satellite	2310-2360 MHz

Table 2. Evaluated DAB Systems.

interference occurs when FM signals reflect from large objects, such as buildings and mountains, causing several time-delayed versions of the same signal to arrive at the receiver.

When tested with five common household, portable, and auto receivers with known operating characteristics, IBOC FM DAB produces a significant impairment to the quality of the FM stereo audio on its "host" analog station. IBOC signals produce objectionable background noise in FM analog receivers. Many of the test reports from expert listeners said that the quality of the FM stereo analog service was "worse" or "much worse" when the station was carrying an IBOC DAB signal. IBOC impairments to the FM stereo service are more substantial on home tuners than on auto receivers, probably due to the reduced bandwidth of the latter.

If two FM stations having a first or second-adjacent channel relationship (and standard geographical spacing) were both to implement IBOC, their useful DAB service areas would be significantly less than their analog coverages in the zone between the two stations.

FM IBOC system performance and interference impairment worsens significantly in the presence of multipath. Of the IBOC systems, the AT&T system performed best in a multipath environment, although failures still occurred under certain conditions. The USA Digital FM-1 and FM-2 systems generally produced degraded performance (or failed completely) whenever multipath was added to the signal.

If two neighboring first-adjacent channel AM stations were both to implement IBOC DAB, the digital signals would fail wherever the desired station's signal is not at least 34 times stronger than that of the undesired station. Many AM stations in urban markets would experience DAB coverage that is substantially smaller than their AM service areas. Nighttime AM DAB service would likely be impractical for most stations, due to the presence of strong adjacent-channel skywave signals.

Digital Radio For The Emerging World

Digital radio is now being provided to the underdeveloped world. A satellite communications company named WorldSpace is setting up a network of three satellites, including "AfriStar," "AsiaStar," and "AmeriStar," to provide digital audio information services to Africa, Asia, and Latin America.

Each satellite provides three transmission beams that can support 50 channels each, carrying news, music, entertainment, and education, and including a computer multimedia service. Local, regional, and international broadcasters are working with WorldStar to provide services.

Low-cost DAB radio receivers are now available from various Japanese manufacturers, and WorldSpace has worked with Thomson Broadcast to introduce a village communications center known as a Telekiosk to bring communications services to rural areas. The Telekiosks are self-contained and are available as fixed or mobile units.

Even the Eureka 147 DAB system that has been adopted outside the United States has been slow to catch on. Broadcasters in several countries have begun to offer service, but the audience remains infinitesimally small. This is certainly due in part to the non-availability of affordable receivers, although this may change with the recent development of a new Eu147 receiver chipset from Philips.

While it is clear that the digital radio services will be competitive with audio alternatives to radio listening, it is unclear how the market will respond. As it stands, the information services market is near saturation. The very same services digital radio expects to provide are currently being provided via pagers, via voice mail, via superwatch. Consequently, digital radio's impact on the market may be far less that what is expected.

For more information, contact The World DAB Forum at www.worlddab.org, the Eureka 147 Consortium at www.eurekadab.org, and iBiquity Digital's IBOC technology at www.ibiquity.com. ■

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